Patent claims

1. Method of generating a control program, according to which a laser-beam spot is guided, while being controlled with respect to position and time, over a cornea to be corrected, so as to ablate a predetermined ablation profile therefrom,
characterised in that, when generating the control program, the effect of the angle between the laser beam (68) and the corneal surface on the energy density of the laser-beam spot incident on the corneal surface is taken into account.

2. Method according to Claim 1, characterised in that, when generating the control program, the effect of the distance r of the incidence point (58) of the laser-beam spot centre on the cornea (54) from an axis running parallel to the laser-beam direction, which meets the corneal surface at a right angle (z axis), is taken into account, and account is taken of the fact that the energy density F of the emitted laser-beam spot of radius r_s is reduced to F/kl(r), in the case of a cornea assumed to be hemispherical with radius R, when incident on its curved surface (54), where

$$kl(r) = \frac{A_{eff}(r)}{A_0} = \frac{A_{eff}(r)}{\pi \cdot r_s{}^2}$$

and

$$A_{eff}(r) = \int_{-rs}^{rs} \int_{-\sqrt{rs^2-x^2}+r}^{\sqrt{rs^2-x^2}+r} \sqrt{1+\left(\frac{d}{dx} f(x,y)\right)^2 + \left(\frac{d}{dy} f(x,y)\right)^2}\, dx\, dy$$

with

$$z = f(x,y) = f(r) = \sqrt{R^2 - x^2 - y^2} = \sqrt{R^2 - r^2},$$

$r = (x^2 + y^2)^{1/2}$

where x, y, z are the coordinates of the incidence point (58) of the laser-beam spot centre in a Cartesian coordinate system, in which the origin lies at the sphere centre of the cornea which is assumed to be hemispherical.

3. Method according to Claim 2, characterised in that the formula is applied for the ablation depth achieved owing to a particular laser-beam spot pulse, in that it is reduced to $d \cdot korl(r)$ in relation to the ablation depth d in the case of normal incidence of the laser-beam spot when the laser-beam spot is incident on the curved surface (54), where

$$korl(r) = \frac{\ln\left(\frac{F}{kl(r)F_{th}}\right)}{\ln\left(\frac{F}{F_{th}}\right)}$$

and F_{th} is the energy-density threshold above which ablation takes place, and in that, when generating the control program, this formula is used to adjust the control of the laser beam in accordance with the desired ablation depth.

4. Method according to Claim 1 or 2, characterised in that, when generating the control program, account is also taken of the fact that a fraction of the laser-beam energy incident on the corneal surface is reflected away.

5. Method according to Claim 4 when dependent on Claim 2, characterised in that, when generating the control program, account is taken of the fact that, in the case of the cornea assumed to be spherical, the unreflected fraction of

the energy density F/k1(r) of the laser-beam spot incident on the curved surface is given as $(1-k2(r))\cdot F/k1(r)$, where

$$k2(r)=\frac{q_{\perp}^{2}(r)+q_{\parallel}^{2}(r)}{2},$$

with

$$q_{\perp}(\alpha_1)=\frac{\sqrt{n^2-\sin^2(\alpha_1)}-\cos(\alpha_1)}{1-n^2}$$

$$q_{\parallel}(\alpha_1)=\frac{n^2\cos(\alpha_1)-\sqrt{n^2-\sin^2(\alpha_1)}}{n^2\cos(\alpha_1)+\sqrt{n^2-\sin^2(\alpha_1)}}$$

where $\pi/2-\alpha_1$ is the angle between the laser beam and the corneal surface, where

$$\alpha_1(r)=\operatorname{atan}\left(\frac{r}{\sqrt{R^2-r^2}}\right) \quad \text{with} \quad 0 \le r^2 < R^2.$$

and n is the empirically determined refractive index of the cornea at the wavelength of the laser beam which is used.

6. Method according to Claim 5, characterised in that the formula is applied for the ablation depth due to a particular laser-beam spot pulse, in that it is reduced to $d\cdot kor(r)$ in relation to the ablation depth d in the case of normal incidence of the laser-beam spot when the laser-beam spot is incident on the curved surface (54), where

$$kor(r)=\frac{\ln\left(\frac{(1-k2(r))\cdot F}{k1(r)\cdot F_{th}}\right)}{\ln\left(\frac{F}{F_{th}}\right)}.$$

and F_{th} is the energy-density threshold above which ablation takes place, and in that, when generating the control program, this formula is used to adjust the control of the laser beam in accordance with the desired ablation depth.

7. Method of generating a control program, according to which a laser-beam spot is guided, while being controlled with respect to position and time, over a cornea to be corrected photorefractively, so as to ablate a predetermined ablation profile therefrom, characterised in that, when generating the control program, the effect of the angle between the laser beam and the corneal surface on the fraction of the laser-beam energy incident on the corneal surface which is reflected away is taken into account.

8. Method according to Claim 7, characterised in that, when generating the control program, the effect of the distance r of the incidence point (58) of the laser-beam spot centre on the cornea from an axis running parallel to the laser-beam direction, which meets the corneal surface at a right angle (z axis) is taken into account, and account is taken of the fact that, in the case of the cornea assumed to be hemispherical with radius R, the unreflected fraction of the energy density F of the laser-beam spot incident on the curved surface is given as $(1-k2(r))\cdot F$, where

$$k2(r)=\frac{q_{\perp}^{2}(r)+q_{\parallel}^{2}(r)}{2},$$

with

$$q_{\perp}(\alpha_1)=\frac{\sqrt{n^2-\sin^2(\alpha_1)}-\cos(\alpha_1)}{1-n^2}$$

$$q_n(\alpha_1) = \frac{n^2 \cos(\alpha_1) - \sqrt{n^2 - \sin^2(\alpha_1)}}{n^2 \cos(\alpha_1) + \sqrt{n^2 - \sin^2(\alpha_1)}}$$

where $\pi/2-\alpha_1$ is the angle between the laser beam and the corneal surface, where

$$\alpha_1(r) = \operatorname{atan}\left(\frac{r}{\sqrt{R^2 - r^2}}\right) \quad \text{with} \quad 0 \le r^2 < R^2.$$

and n is the empirically determined refractive index of the cornea at the wavelength of the laser beam which is used.

9. Method according to Claim 8, characterised in that the formula is applied for the ablation depth due to a particular laser-beam spot pulse, in that it is reduced to $d \cdot kor2(r)$ in relation to the ablation depth d in the case of normal incidence of the laser-beam spot when the laser-beam spot is incident on the curved surface, where

$$kor2(r) = \frac{\ln\left(\frac{(1-k2(r)) \cdot F}{F_{th}}\right)}{\ln\left(\frac{F}{F_{th}}\right)}$$

and F_{th} is the energy-density threshold above which ablation takes place, and in that, when generating the control program, this formula is used to adjust the control of the laser beam in accordance with the desired ablation depth.

10. Method of generating a laser-beam profile which is projected with a wide field or in slit form onto a cornea to be corrected, so as to ablate a predetermined ablation profile therefrom,
characterised in that, when generating the laser-beam profile, the effect of the angle between elementary beams of the laser-beam profile and the corneal surface on the energy density of the elementary beam incident on the

corneal surface and/or on the fraction of the laser-beam energy incident on the corneal surface which is reflected away, is taken into account.

11. Method according to one of the preceding claims, characterised in that before generating the program for the positions at which the laser beam is to be incident, the local radius of curvature of the cornea is determined, and the angle between the laser beam and the corneal surface and/or the effect of this angle on the energy density of the laser-beam spot or elementary laser beam incident on the corneal surface and/or the effect of this angle on the fraction of the laser-beam energy incident on the corneal surface which is reflected away, is derived therefrom.

12. Method according to one of the preceding claims, characterised in that, for the control, and preferably for the time control, account is taken of the fact that the angle between the laser beam and the corneal surface changes during the ablation.

13. Method according to one of the preceding claims, characterised in that the program is configured so that, during the ablation, it can pick up information about the position of the eye with the cornea to be corrected and, when this position changes, it takes into account the change in the angle between the laser beam and the corneal surface and/or the change in the effect of this angle on the energy density of the laser-beam spot or elementary laser beam incident on the corneal surface and/or in the effect of this angle on the fraction of the laser-beam energy incident on the corneal surface which is reflected away.

14. Electronic computer (48) for delivering control signals to control a laser beam, characterised in that the computer (48) is programmed with, and runs, a control program that has been generated using the method according to one of Claims 1 to 13.

15. Device for photorefractive corneal surgery of the eye to correct sight defects, having:

- an instrument (12, 14, 16, 22, 24, 28) for measuring the entire optical system of the eye to be corrected,
- means (48) for deriving an ablation profile from the measured values,
- a laser-radiation source (30) and means (32, 38, 40, 48) for controlling the radiation in accordance with the ablation profile, characterised in that the control means comprise an electronic computer (48) which runs a control program that has been generated using the method according to one of Claims 1 to 13.

16. Device according to Claim 15, in which the electronic computer (48) runs a control program that has been generated according to Claim 11, the local radius of curvature having been determined by the instrument for measuring the entire optical system of the eye to be corrected.

17. Device according to Claim 15 or 16, in which the electronic computer (48) runs a control program that has been generated according to Claim 13, the device having an instrument (28, 42, 44) for determining the position of the eye, which instrument sends information about the position of the eye to the computer (48).